1,087,565

PATENT SPECIFICATION 1,087,565

DRAWINGS ATTACHED.

Date of Application and filing Complete Specification: *Jan. 4, 1965.* *No. 265/65.*

Application made in United States of America (No. 336,717) on Jan. 9, 1964.

Complete Specification Published: Oct. 18, 1967.

Index at Acceptance:—B1 D(1A, 1B1, 1B2, 1E, 1F, 1G, 2J1B1, 2J1B2, 2J1C3, 2J1D, 4B).

Int. Cl.:—B 01 d 27/10.

COMPLETE SPECIFICATION.

Filter Assembly.

We, PALL CORPORATION, a Corporation organised under the laws of the State of New York, United States of America, of 30 Sea Cliff Avenue, Glen Cove, New York, United States of America, and THE BOEING COMPANY, a Corporation organised under the laws of the State of Delaware, United States of America, of P.O. Box 3707, Seattle 24, Washington, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to filter assemblies, and more particularly to filter assemblies especially designed for use with hydraulic systems of aircraft, to remove a substantial proportion of very fine incident particles.

So many extraordinary demands are made upon the hydraulic systems of aircraft, that the surprising thing is not that there is an occasional failure, but that the systems are as effective as they are. The hydraulic fluids used must withstand temperatures ranging from $-65°F$ to as high as $275°F$, and occasionally even higher, and must be completely flowable and operative in the system under these conditions.

Wear and abrasion of parts result in the production of very fine particles, usually less than 5 microns in diameter. While these fine particles are so small that individually they cause no obstruction, there is nonetheless a tendency for sedimentation of such particles in regions where the rate of flow is rather low and for collection of such particles in the small (often 5 microns or less) clearances in servo valves and other components. In the course of time, serious obstructions can be built up even from such small particles. Indeed, it is the very fine particles that are usually responsible for valve failure in such systems, nowadays, since these are the particles not removed by conventional filters. In addition, it is particles of this size that cause wear in pumps since it is only these particles that can readily enter the clearances between the moving parts of a pump.

Maintenance of a clean hydraulic fluid of course requires efficient filtration. In this respect, the fine particles present a special problem, because it is quite difficult to prepare a filter element capable of removing very small particles that has a sufficient flow capacity to meet the flow requirements of the typical aircraft system. In normal flight of a typical commercial transport aircraft such as the Boeing 720, a flow of hydraulic fluid of the order of 5 gallons per minute or less is encountered, but whenever the landing gear is operated, a higher flow rate of 40 gpm is required. Flow capacity of a filter is of course a function of surface area and micron removal ratings and in the limited space requirements of aircraft, it has not until very recently been possible to provide a filter element sufficiently rugged for aircraft hydraulic system service and having a fine enough incident particle removal rating, and a high enough flow capacity, to meet these requirements. The result has been that in aircraft, at least, it has not been possible to design a filter element that is capable of removing a substantial proportion of very fine incident particles.

According to the invention a filter assembly comprises a housing having inlet and outlet passages, a primary filter element disposed in the housing, a secondary filter element disposed in the housing and fixed in relation to the primary filter element, a flow responsive device for controlling flow disposed in the housing in the line of fluid

flow from the inlet passage to the primary and secondary filter elements, the primary filter element receiving fluid for filtration from the flow responsive device, and delivering filtered fluid to the outlet passage of the housing, the flow responsive device normally closing off flow to the secondary filter element but permitting the latter to receive fluid for filtration from the inlet passage of the housing so as to deliver such filtered fluid to the outlet passage of the housing whenever said flow responsive device is opened, the flow responsive device permitting a fluid rate of flow not exceeding a predetermined quantity to the primary filter element at all times, and being responsive to a predetermined fluid flow in the inlet passage to open the passage leading therefrom to the secondary filter element, whereby whenever the rate of flow to the assembly exceeds the rate of flow permitted by the flow responsive device to pass to the primary filter element, the device is opened to allow flow of fluid directly to the secondary filter element.

Thus in accordance with the invention, a filter assembly is provided that is capable of removing a substantial proportion of very fine incident particles, and preferably all incident particles over 3 microns in diameter, and that is capable of supplying a flow rate as high as may be desired, without any real upper limit, except that imposed by conventional filter elements now in use. A filtered flow is provided at all flow rates, but at flow rates in excess of a predetermined maximum, only a portion of the flow is filtered through the primary filter element. The remainder is diverted by the flow responsive device, through the secondary filter, of normal flow capacity but capable only of removing most of the larger incident particles, preferably at least those incident particles over 15 microns in diameter. The normal flow, plus a safety margin, through the primary filter element is the maximum required for normal operational flow in the system in which the element is installed. Only when extraordinary requirements are made upon the flow, beyond this maximum, does the flow responsive device divert the incremental portion of the flow through the secondary filter element. Since such extraordinary flow requirements are usually made only for short periods, less than 5% of the total flight time, the filter assembly of the invention effectively keeps the hydraulic fluid substantially free from particles larger than will pass the primary filter element, since any such particles that may enter the fluid during the times of extraordinary flow are removed later in the course of normal flow.

As a further feature, the filter assembly of the invention provides for maintenance of a filtered flow through the secondary filter element whenever the primary element is clogged or so obstructed that the flow-through results in a pressure differential across that element above a predetermined minimum. In this event, also, the flow responsive device provided diverts through the secondary filter element flow above that which the partially or fully clogged primary filter element can pass.

A second by-pass is provided for the secondary filter element, so that when this element becomes clogged, or so obstructed as to increase the pressure differential across it to above a predetermined minimum, then all flow through the filter partially or completely by-passes both the primary and the secondary filter elements. Normally, there is ample time after the primary element has become obstructed for the filter element to be serviced before the secondary filter element becomes clogged. Thus, the second by-pass line would come into use only in the event of an emergency of rather unusual character.

Differential pressure indicators can be provided, indicating the reaching of a predetermined pressure differential across the primary filter element, and across the secondary filter element, so that an indication is given to the operator that the primary or secondary filter element or both have become clogged, and require servicing.

For control of the diversion of fluid from the primary filter element at flow rates above the predetermined maximum, as well as diversion whenever the primary filter element becomes obstructed such that the pressure differential across it reaches a predetermined minimum, there is provided as one preferred embodiment of the flow responsive device a combination of a flow-restricting orifice, limiting rate of flow through it to a maximum value, and a pressure-sensitive valve so designed as to be actuated by an increase in fluid pressure due to an increase in the velocity of flow to the filter assembly. The rate of flow through the orifice is limited to a maximum value since an increase in flow beyond this maximum results in an increase in fluid pressure which opens the pressure-sensitive valve. Since this increase in fluid pressure is proportional to rate of flow, the pressure-sensitive valve is responsive to changes in volumetric flow rate and consequently to changes in flow demand, made upon the filter assembly of the invention.

The orifice is placed in the line of flow between the inlet to the filter assembly and the primary filter element, and preferably, in an inlet passage, while the pressure-sensitive valve is placed in the line of flow between the inlet and the secondary filter element.

The orifice considerably reduces the diameter of the passage available for flow, such as in the inlet passage, and as a consequence of this reduction in diameter, the flow through it is limited. The pressure-sensitive valve is desirably in the form of a spring-biased poppet reciprocating between open and closed positions, and having its face exposed to fluid pressure in the inlet line. The valve is biased in the closed position, and remains stationary, in position against the valve seat, while the flow is within the limits of the orifice. Under such normal flow conditions, a steady state exists in which the force due to fluid pressure on the inlet side of the pressure-sensitive valve is less than will open the valve and the valve remains stationary. However, when the volumetric flow rate increases, and exceeds the limited flow permitted through the orifice, the fluid pressure in the inlet increases, and in time exceeds the biasing force tending to hold the valve closed against the inlet flow. The valve is designed to be opened whenever the fluid pressure at the inlet increases above a predetermined value.

The pressure-sensitive valve is so positioned in the fluid line, such as the inlet passage, as under normal flow conditions to close off a line leading to the secondary filter element. The result is that all flow must pass through the orifice into the primary filter element. At the predetermined fluid pressure on the valve face on the inlet side of the pressure-sensitive valve, the minimum value of which is determined by the flow requirements of the system, the valve is actuated in a manner to open the passage between the inlet and the secondary filter element.

With appropriate selection of the spring-biasing force holding the pressure-sensitive valve closed, the amount of opening can be proportional to the magnitude of the fluid pressure, and thus the amount of diversion of flow to the secondary element can be made directly dependent upon the rate of flow. While the valve is open, flow to the primary filter element continues at the normal but maximum rate through the orifice. Thus, at all times flow is supplied to and through the primary filter element, while it remains unobstructed. Hence, at flow rates above the predetermined maximum, there is flow through both the primary and the secondary filter elements until they become completely clogged. The filter is thus able to accommodate itself to the increased demand for flow, and all of the flow through the filter assembly is still filtered.

In the preferred embodiment of the flow responsive device of the invention which comprises structurally an orifice, and a spring actuated poppet biased against a valve seat in a position to close off a line to the secondary filter element, in which the poppet is exposed to fluid pressure in the inlet, and the orifice connects the inlet with the passage leading to the primary filter element at all times, the biasing pressure exerted by the spring against the poppet can be adjusted as required by appropriate selection of the spring and spring tension, and the dimensioning of the orifice is matched with the compressive force of the spring and the dimensioning of the poppet exposed to fluid pressure, so as to obtain actuation of the pressure-sensitive valve poppet at the predetermined fluid pressure at the inlet.

Preferably, a relief valve is provided which is actuated whenever the fluid pressure at the inlet exceeds the pressure in the passage to the secondary filter element on the other side of the primary filter element by a predetermined amount. Thus, in the preferred embodiment, whenever the fluid's passage through the primary filter element becomes obstructed, so that the total pressure differential between the inlet passage and the passage to the secondary filter element exceeds a predetermined maximum, the relief valve is actuated, exposing the line to the secondary filter element, by-passing the primary element, and filtered flow continues by way of the secondary filter element, on an emergency basis until the primary element can be serviced. The relief valve can be the same valve as the pressure-sensitive valve previously described.

Preferably, a spring-biased poppet valve is also used to control relief flow around the secondary filter element in case of plugging or obstruction, to a flow-reducing degree, of the secondary filter element.

The flow responsive devices can be constructed of any durable material inert to the fluid being circulated through the system. Metal devices, such as those made of aluminum, stainless steel, and other stainless alloys, are preferred, but it is also possible to fabricate the device from synthetic polymers and cellulose derivatives, such as polytetrafluoroethylene, polypropylene, polyethylene, polystyrene, nylon, polyoxymethylene, acrylonitrile rubbers, and fluorocarbon rubbers.

The primary filter element of the invention is selected to meet the system requirements for incident particle removal. As has been stated, hydraulic systems of aircraft may require the removal of all incident particles as small as 3 microns in diameter. The particle removal rating of the primary filter element is not critical, and can range from 0.035 to 10 microns or higher, depending on the system parameters.

As the primary filter element, any filter material can be employed. Sheet filter material can be used, such as porous sheets

made of paper, fiber mats and felts, plastic membranes, sintered particulate material, and wire mesh and sinter-bonded wire mesh, disclosed in British Specification No. 830,908 and United States Specification No. 3,049,796, in which the wires or particles are made of metals or natural or synthetic plastic materials, such as stainless steel, aluminum, glass, ceramic materials, polyvinyl chloride, polyethylene, polypropylene, polystyrene, and polytetrafluorethylene.

Because filter materials having such small particle removal ratings have a relatively low flow capacity, it is preferred to form the primary filter element in pleats, convolutions or corrugations, so as to provide a greater surface area in a small volume.

The secondary filter element is selected primarily for flow capacity, so as to pass the maximum required volume of fluid per unit time under the maximum flow demands of the system, and is preferably also selected so as to give the smallest particle removal ratings obtainable at such flow capacity.

The particle removal rating of the secondary filter element is in no way critical, and can range from 3 to 50 microns or higher, depending on the requirements of the system. Particles passed in flow through the secondary filter element are temporarily in the system, however; the primary filter element normally cleans up such particles during normal flow.

If the primary element is made of material (for example, sintered powder, felt or paper) which may release particles or fibers from its downstream surface, the secondary filter should preferably be fine enough to remove all such particles or fibers.

Secondary filter elements are available which have the required flow capacity. Such elements are made of wire mesh and of sinter-bonded wire mesh such as is described in British Specification No. 830,908 and United States Specification No. 3,049,796, and sinter-bonded wire mesh having a surface layer of sinter-bonded metal particles, such as is described in United States Specification No. 3,061,917. Also useful are filter elements made of sinter-bonded metal particles, such as sheets of porous stainless steel and other stainless alloys, bronze, aluminum and steel. Any of the materials described above for use in the primary filter element can also be employed for the secondary filter element, but with a larger pore diameter so as to remove only the larger incident particles, for the required greater flow capacity.

The secondary filter element also preferably is formed in pleats, convolutions or corrugations, for greater surface area.

Figure 1 is a longitudinal section through a filter assembly or unit in accordance with the invention, showing the filter head and filter bowl, and the elements disposed therein.

Figure 2 is a cross-sectional view of the filter unit of Figure 1, taken along the lines 2—2 and looking in the direction of the arrows.

Figure 3 is a cross-section of the bowl portion of the filter unit of Figure 1, taken along the line 3—3 and looking in the direction of the arrows.

The filter unit shown in the drawings comprises a head 1 provided with a threaded inlet port 2 and a threaded outlet port 3, adapted to be fitted with suitable pipe connections. Port 2 leads to an internal passage 4. Port 3 serves as the exit for internal passage 5, which extends laterally and then downwardly to a port 6 in the central portion of the lower face of the head 1.

The flow control device comprises the combination of an orifice 10 disposed at the inner end of passage 4 and controlling flow from passage 4 to the primary filter element, and a pressure-sensitive valve 11 disposed in a socket 19 at one side of passage 4. The orifice 10 opens on its inlet side into passage 4 of the head, and on its outlet side into passage 7 in the head. Passage 7 extends first laterally and then downwardly, leading to a port 8 on the lower face of the head.

The pressure-sensitive valve 11 comprises a spring-biased valve poppet 15, fitting snugly against the side walls of the socket 19, and reciprocating therein against the compression spring 13, which is seated against the far end of the socket. In the closed position of the valve, the poppet 15 seats against a valve seat 20. Flange 21 in the passage 4 retains the poppet in the socket 19. Thus, entry of fluid from passage 4 into passage 16 normally is prevented by poppet 15, when in the closed position against valve flange 21. When the poppet 15 is moved away from the valve seat 20 passage 16 is opened to flow of fluid from the inlet passage 4 through passage 16 to port 17 on the lower face of the head.

The head 1 has a downwardly extending portion 28, provided with an outwardly extending lip 29, and to this lip is attached a filter bowl 30 by means of the V-ring clamp 31 and enclosing ring 32, thus providing easy removal of the filter bowl from the head. A leak-proof seal is provided between the outwardly flared upper lip 33 of the filter bowl and the lower face of lip 29 by means of the O-ring seal 34.

Disposed in the bowl 30 are a primary filter element 40, and a secondary filter element 50. The filter element 40 shown in the drawing is made of a preferred filter material, epoxy resin impregnated cellulose paper. The material is in corrugated form,

as is best seen in Figure 3. The corrugations are both supported from within and protected from without by cylindrical perforated cores of sheet metal, such as aluminum or stainless steel, the inner core being designated 41 and the outer cover 42.

The assembly of the corrugated primary filter core and cover is held between upper and lower end caps 43 and 44, respectively. Each of the end caps 43 and 44 is provided with central apertures 45 and 45^1, respectively. On each end cap, abutting the central apertures, are pieces 46 and 47 respectively, which are bonded to the end caps, and turned away from the end cap and then inwardly, to form with the caps the grooves within which are captured O-rings 48 and 49.

The opening in the lower end cap 44 is closed off by the bottom cap 60. The cap 60 has an upwardly extending reentrant portion 61, fitting tightly within the opening of the end cap 44, and engaging the inner periphery of the end cap and of the inner piece 47. A leak-proof seal with the cap 60 is formed by the O-ring 49.

The cap 60 is secured in the opening 45^1 by the end plate 62, the periphery of which extends beyond the opening 45^1 in the end cap, and caps 60 and plate 62 are locked together by the rivet 64. The lower flanges 65 of the rivet 64 retains a spring 66, the other end of which is biased against the bottom 67 of the bowl 30.

The head 1 is provided with a second inner downward tubular extension 35, over which the opening 45 in the top end cap 43 fits, and the O-ring seal 48 provides a leak-proof seal between the end cap and the head portion 35. The spring 66 at the bottom of the bowl holds the cap 43 and consequently the primary filter element 40 tightly against the head 1. As a result, the outer cover 42 surrounding primary filter element 40 and the filter bowl 30 define between them a space 70 just inside the wall of the bowl. The port 8 of the head 1 opens into this space, but the only exit is through filter element 40. It is thus evident that fluid entering through the inlet 2, passages 4 and 7, and port 8 of the head, into the space 70, can only emerge from the bowl 30 by passing through cover 42, the primary filter element 40, and core 41, in sequence.

The secondary filter element 50 is concentrically disposed within the inner core 41, at a point spaced therefrom, thereby defining a space 71 between the outer surface of the secondary filter element and the core 41. The port 17 of the head opens into the bowl 30 directly over the space 71. The secondary filter element is made of a sintered wire mesh, prepared in accordance with British Specification No. 830,908 and United States Specification No. 3,049,796, and having a surface of sinter-bonded fine metal powder, in accordance with United States Specification No. 3,061,917. In this case, both the sintered wire mesh and the metal powder are made of stainless steel. This element, which is also in corrugated form, is supported on a perforated metal cylinder core 51 of aluminum or stainless steel, and the resulting composite welded or brazed to top and bottom end caps 52 and 53, respectively, in accordance with the process and structure of United States Specifications Nos. 3,007,579 and 3,007,238. The bottom end cap 53 is closed. The top end cap 52 has a central opening 55, and is turned inwardly at the opening to form a groove 56 within which is placed an O-ring 57 which seals to the bottom surface 36 at extension 35 of head 1. The bottom plug 60 inserted in the central opening of end cap 44 of the primary element positions the secondary element 50 correctly with respect to the head 1 and passage 6.

A relief valve assembly is provided, between passage 71 and passage 5, disposed in a socket 80 of the head, composed of a poppet 81 above space 71 and in a passage 85 leading to passage 5. The valve is biased by a compression spring 82 against a sealing surface 83 in the passage 85. The poppet seals against sealing surface 83 at the lower end of socket 80.

The poppet 81 normally is in the position shown, closing passage 85, and thus the space 72 within the secondary filter element 50, port 6 and exit passage 5 are completely closed off from the passage 71, and entry of fluid thereto is obtained only by passage through the secondary filter element 50. Accordingly, while the relief valve 81 is closed, fluid from the primary filter element 40 in order to reach exit passage 5 and outlet port 3 of the head 1, flows across space 71 and through the secondary filter element 50 into the space 72. Whenever the poppet 81 moves away from its seat against the sealing surface 83, however, and this occurs at a predetermined pressure differential across the secondary filter element 50, between space 71 and space 72, a path is opened directly to passage 5, so that flow can now continue by-passing the secondary filter element 50, to the outlet port 3 of the head 1. Such flow is an unfiltered flow, in event of an emergency only.

At the bottom wall 67 of the filter bowl 30, there is provided a drain port 90, opened by turning the hexagonal nut 91. In this manner, when removal of the bowl is required for servicing of the filter elements 40 and 50 or other parts of the filter unit, the bowl can be drained of fluid before removing the V-ring clamp 31 and ring 32.

Also provided in the head 1 are two pres-

sure indicators 100 and 101. These indicators preferably are of the magnetic type, as described and claimed in British Specification No. 891,246. Indicator 100 is connected by line 103 to passage 16 of the head, on the other side of the orifice 10, and by passage 102 with inlet passage 4 of the head, and thus detects any pressure differential in excess of a predetermined maximum between passages 4 and 16. Inasmuch as during normal operations, passage 4 is directly connected through passage 7 of the head with space 70 on the unfiltered fluid side of the primary filter element 40, and passage 16 is connected directly to space 71 on the other side of the primary filter element 40, pressure indicator 100 detects the pressure differential across the primary filter element 40. Thus, it will give a signal whenever the predetermined pressure differential across this element has been exceeded, indicating that the filter element has been plugged or sufficiently obstructed so as to reduce flow therethrough to below the predetermined minimum.

Pressure indicator 101 is connected by passage 105 to the space 71 in the bowl, and by passage 106 to the outlet passage 5 of the head. It will thus give a signal whenever a predetermined minimum pressure differential between these two passages has been exceeded. Passage 5 is on the outlet side of secondary filter element 50 whereas space 71 is on the upstream side of the secondary element. Thus indicator 101 will warn when the secondary filter element becomes plugged. When this occurs, the pressure differential across it can reach the level at which indicator 101 is activated, and before the pressure differential at which relief valve 81 is opened, so that the indicator 101 gives an indication of plugging only of the secondary filter element 50, and prior to the beginning of completely unfiltered flow.

The various paths of flow of fluid through the filter unit under the varying flow rates in the system can now be understood. Normally, at all flow rates below a predetermined maximum, say 5 gallons per minute, fluid to be filtered enters the filter unit at port 2, proceeding through passage 4 of the head, and then through the orifice 10 to passage 7 of the head, emerging from the head at port 8 into the space 70 between the exterior of the primary filter element and the inner wall of the bowl 30. It then passes through the exterior cover 42 of the primary filter element, the primary filter element 40 and the internal core 41 emerging into the space 71 between the primary and secondary filter elements. Next, it passes through the secondary filter element 50 and the core 51 into the space 72 enclosed by core 51 emerging from the bowl 30 at port 6 into the exit passage 5 of the head, leaving the filter unit at outlet port 3.

Inasmuch as the primary filter element 40 removes small particles, and the secondary filter element only the larger particles, in this normal line of flow the secondary filter element provides no effective contaminant filtering action. It can, however, prevent migration of any material that may become detached from the primary filter element 40.

Thus, in normal flow the filter unit is operating at the maximum particle removal rating, and no particles which have a diameter in excess of say, 3 microns, will pass the filter unit. This efficient operation is obtained at all normal flow rates below the predetermined maximum at which pressure-sensitive valve 11 is actuated.

Whenever a higher flow capacity is required in the system, the pumps operating the fluid will of course provide more flow, and the rate of flow of fluid to the filter unit at inlet 2 will increase. As the rate of flow into the filter unit increases, the limited capacity of the flow through the orifice 10 is reached, with the result that the fluid pressure increases to the value at which the pressure-sensitive valve 11 is set to open, and the valve poppet 15 moves away from the seat 20 at the end of the socket 19, thus exposing passage 16 to fluid flow. While this is occurring, flow continues through the orifice 10 at the normal volume of say 5 gallons per minute. Since the volume of flow that can pass through the orifice is strictly limited by the dimensions thereof, accordingly the excess fluid flow now passes through passage 16, and emerges from the head at port 17. Port 17 in the head directly faces the space 71 between the primary and secondary filter elements, and thus the excess flow by-passes the primary filter element 40, and, passing through only the secondary filter element 50, emerges into the passage 72 enclosed by the filter element, thence leaving the filter bowl 30 at port 6 and exit passage 5. In the course of such flow, it is thoroughly mixed with the filtered flow which continues to pass through the primary filter element 40. The fluid now delivered by the filter unit to the system is therefore composed of fluid passing through the primary filter element, and thus effectively stripped of all particles more than 3 microns in diameter, together with flow passing only through the secondary filter element, and stripped only of particles in excess of say, 15 microns, in diameter. The system can tolerate such a mixed flow for a considerable period of time, but as a matter of fact this flow is continued only for so long as the excess flow demand is made upon the system. As soon as the flow demand diminishes, and the volume of fluid and rate of flow is restored to normal, the pressure upon the

orifice 10 is correspondingly decreased. The fluid pressure in passage 4 once again decreases, and returns to normal. When the fluid pressure has been reduced to below that at which the pressure-sensitive valve 11 is opened, the valve returns to its seat 20 at the end of socket 19 under the pressure of the spring 13. Passage 16 to the head is accordingly closed off, and all flow by-passing the primary filter element ceases. All the filtered flow accordingly is subjected to the action of the primary filter element 40, and all particles in the system larger than 3 microns in diameter are now removed. Since all of the fluid circulating in the system is eventually recirculated through the primary filter element, any particles which may have escaped the secondary filter element because they are smaller than can be removed thereby, that is, any having a particle size within the range from 15 microns down to 3 microns, will now be removed from the fluid by the action of the primary filter element. Thus, the presence of such particles in the fluid is only temporary, during the period of excess flow requirements.

In the course of use, as the amount of material removed by the primary filter element increases, flow through the primary filter element becomes obstructed. As this happens, the fluid pressure upon the poppet 15 at the inlet face increases, due to the reduction in flow volume through and on the other side of the primary filter element. This results in a corresponding increase in the pressure differential across the valve 11 between passage 4 and passage 16, which communicates through port 17 with the space 71 between the primary and secondary filter elements. Eventually the fluid pressure or force applied to the valve poppet 15 exceeds the predetermined pressure at which the valve poppet 15 will open, and the valve poppet 15 is then pushed away from the seat 20, against the action of the spring 13, thus exposing passage 16 to the flow of fluid. If desired, the spring 13 can be set so that the amount of opening of the valve can be proportional to the fluid pressure upon the poppet. Thus, flow can continue through the primary filter element for as long a period as possible, until it is plugged completely. At this point, or shortly before, the valve 11 is then fully opened, and all flow passes through only the secondary filter element. Up until that point, only a portion of the flow passes directly to and through, but a sufficient proportion to maintain the required flow volume to be delivered at the outlet port 3.

With the plugging of the primary filter element 40, and the corresponding reduction in pressure observed in passage 16, due to the pressure sensing connections 102 and 103, on each side of the differential pressure indicator 100, this change in pressure between passage 4 and 16 is detected by the indicator, which, at a pressure differential at or preferably just short of the time of opening of the valve 11 to expose passage 16, signals that the primary filter element is clogged. Thus, the operator is made aware of the condition requiring his attention at or before the time when the secondary filter element is put into service, by-passing the primary filter element. The differential pressure indicator 100 is preferably so set that the signal is given continuously until the filter unit is serviced, since it is important that the flow bypassing the primary filter element not be maintained for any longer length of time than is absolutely necessary.

Flow through the secondary filter element 50 into space 72 will continue until the secondary filter element becomes clogged. In the unlikely event that this should occur, the poppet 81 provides a by-pass around the secondary filter element 50. As the secondary filter element 50 becomes obstructed, due to the removal of contaminants, the pressure differential between spaces 71 and 72 will increase, and eventually it reaches the point at which the poppet 81 is forced away from its seat 83, opening the passage 85 between these two spaces. Just before the pressure reaches that point, the change in pressure between that space 71, now in direct connection with passage 4 of the head, and space 72, which is in direct connection with passage 5 of the head, is detected by the pressure indicator 101, which is in direct communication therewith through passage 105 and passage 106. Accordingly, a signal is given at a pressure differential just before the pressure differential required to open the poppet 81. The operator now sees the signals of the two pressure indicators 100 and 101, and knows that both filter elements of the filter unit are out of service, so that servicing of the unit is imperative if satisfactory operation of the hydraulic system is to be continued.

While the configuration of flow described herein is considered preferable, it will be obvious to those skilled in this art that the same functions can be achieved using different mechanisms. For example, other conventional types of flow control device, direct or pilot operated, can be used.

WHAT WE CLAIM IS:—

1. A filter assembly comprising a housing having inlet and outlet passages, a primary filter element disposed in the housing, a secondary filter element disposed in the housing and fixed in relation to the primary filter element, a flow responsive device for controlling flow disposed in the housing in the line of fluid flow from the inlet passage

to the primary and secondary filter elements, the primary filter element receiving fluid for filtration from the flow responsive device, and delivering filtered fluid to the outlet passage of the housing, the flow responsive device normally closing off the flow to the secondary filter element but permitting the latter to receive fluid for filtration from the inlet passage of the housing so as to deliver such filtered fluid to the outlet passage of the housing whenever said flow responsive device is opened, the flow responsive device permitting a fluid rate of flow not exceeding a predetermined quantity to the primary filter element at all times, and being responsive to a predetermined fluid flow in the inlet passage to open the passage leading therefrom to the secondary filter element, whereby whenever the rate of flow to the assembly exceeds the rate of flow permitted by the flow responsive device to pass to the primary filter element, the device is opened to allow flow of fluid directly to the secondary filter element.

2. A filter assembly in accordance with claim 1 including a relief valve set to open at a predetermined pressure differential across the secondary filter element, bypassing the secondary filter element, whenever the secondary filter element becomes obstructed and the pressure differential thereacross exceeds the predetermined value.

3. A filter assembly in accordance with claim 2 in which the relief valve is in the form of a spring-biased poppet valve.

4. A filter assembly in accordance with claim 1 in which the primary filter element has at most a 5 micron particle removal rating and the secondary filter element has at most a 15 micron particle removal rating.

5. A filter assembly in accordance with claim 1 wherein the flow responsive device for controlling flow comprises as one component a flow-restricting orifice.

6. A filter assembly in accordance with claim 1 wherein the flow responsive device for controlling flow comprises a combination of a flow-restricting orifice and a pressure-sensitive valve.

7. A filter assembly in accordance with claim 1 wherein the primary filter element is made of resin-impregnated paper and the secondary filter element is made of sintered wire mesh having a surface of metal particles sinterbonded thereto.

8. A filter assembly in accordance with claim 1 including a differential pressure indicator for detecting and indicating a pressure differential across the primary filter element greater than a predetermined minimum

9. A filter assembly in accordance with claim 1 including a differential pressure indicator for detecting and indicating a pressure differential across the secondary filter element greater than a predetermined minimum.

10. A filter assembly in accordance with claim 1 in which the primary and secondary filter elements are concentrically disposed in the housing.

11. A filter assembly in accordance with claim 1 wherein said flow responsive device for controlling flow includes a relief valve set to open at a predetermined pressure differential across the primary filter element, bypassing primary filter element whenever the primary filter element becomes obstructed and the pressure differential thereacross exceeds a predetermined value.

12. A filter assembly comprising a housing having inlet and outlet passages, a flow-restricting orifice in the inlet passage, a primary filter element disposed in the housing in a manner such that fluid for filtration entering the inlet passage first passes through the orifice and thence passes to the primary filter element, a secondary filter element in the housing normally receiving filtered flow from the primary element and disposed in the housing in a manner to deliver filtered fluid to the outlet passage of the housing, a passage in the housing leading directly from the inlet passage to the secondary filter element in a manner to by-pass the primary filter element and the flow-restricting orifice, a pressure-sensitive spring-biased poppet valve in the said passage and normally closing the passage, the orifice permitting delivery of fluid to the primary filter element at all times, and the pressure-sensitive valve being adapted at a predetermined fluid pressure differential across the valve to open the passage leading directly from the inlet passage to the secondary filter element.

13. A filter assembly in accordance with claim 12 in which the primary and secondary filter elements are concentrically disposed in the housing.

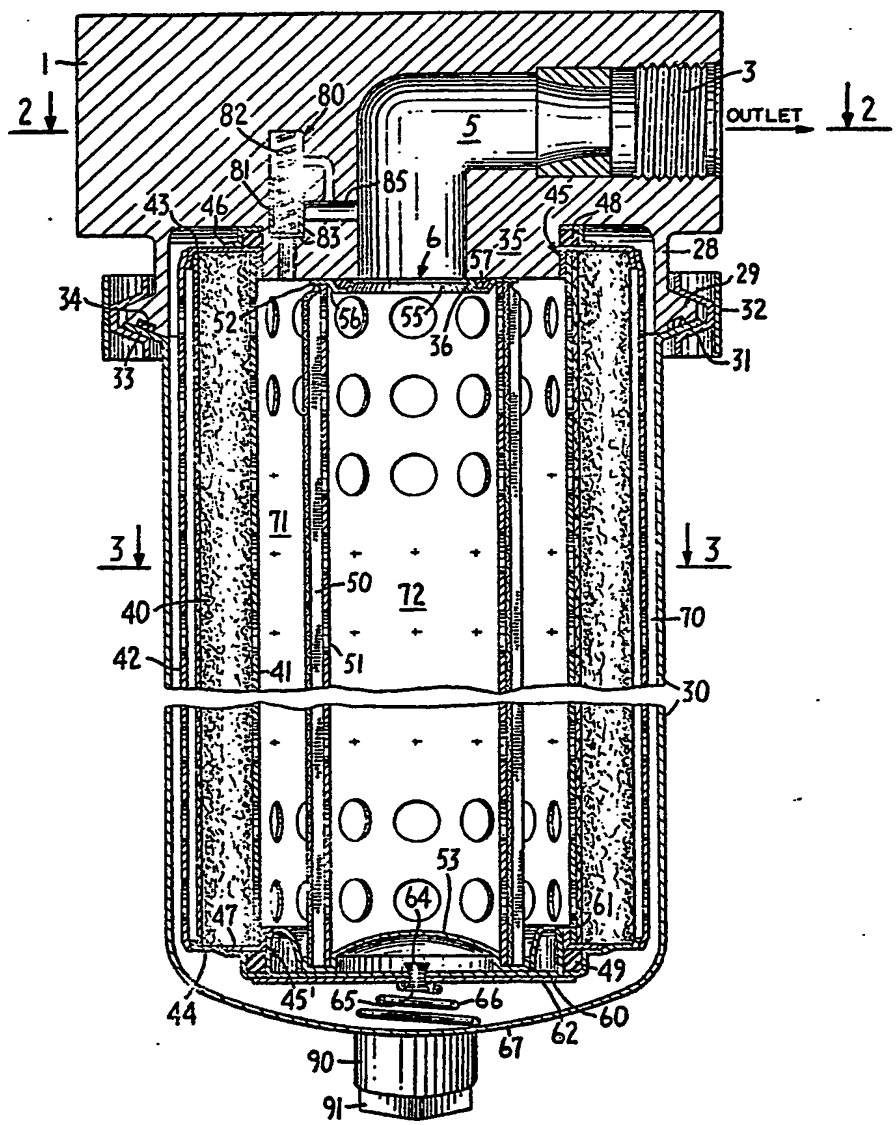
14. A filter assembly in accordance with claim 12 wherein said poppet valve is set to open at a predetermined pressure differential across the primary filter element, bypassing the primary filter element whenever the primary filter element becomes obstructed and the pressure differential thereacross exceeds a predetermined value.

15. A filter assembly constructed, arranged and adapted to operate substantially as herein described with reference to the accompanying drawings.

ARTHUR R. DAVIES,
Chartered Patent Agents,
27, Imperial Square, Cheltenham,
and
320, High Holborn,
London, W.C.1.
Agents for the Applicants.

Abingdon: Printed for Her Majesty's Stationery Office, by Burgess & Son (Abingdon), Ltd.—1967.
Published at The Patent Office, 25 Southampton Buildings, London, W.C.2,
from which copies may be obtained.

FIG. 1



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INLET

2-

1087565 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheets 1 & 2

FIG. 2

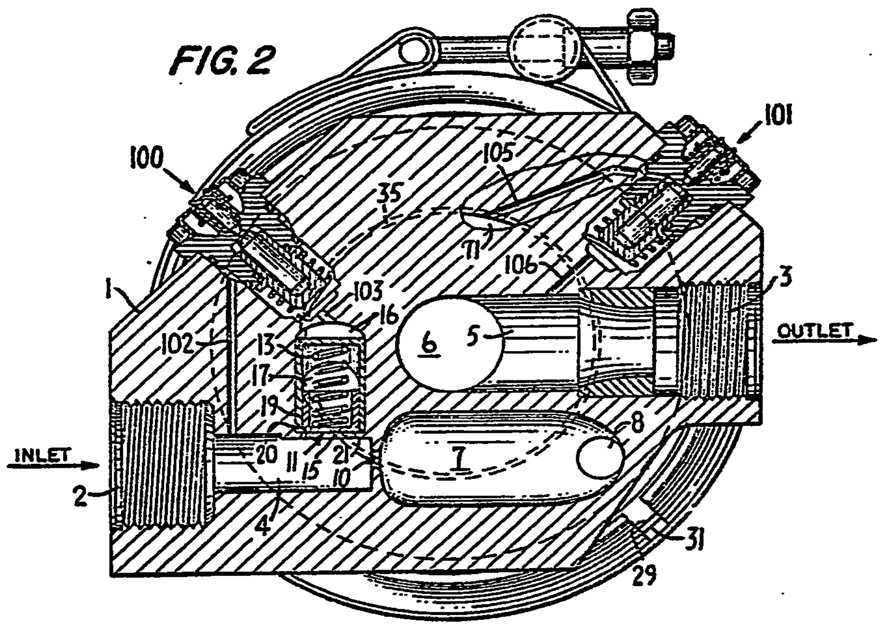
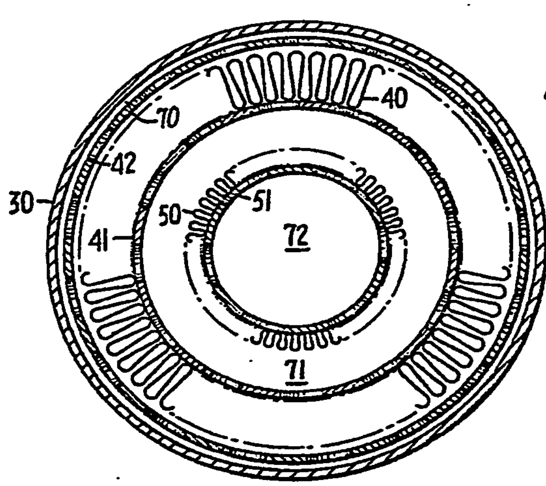


FIG. 3



1087565 COMPLETE SPECIFICATION
2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheets 1 & 2

FIG. 1

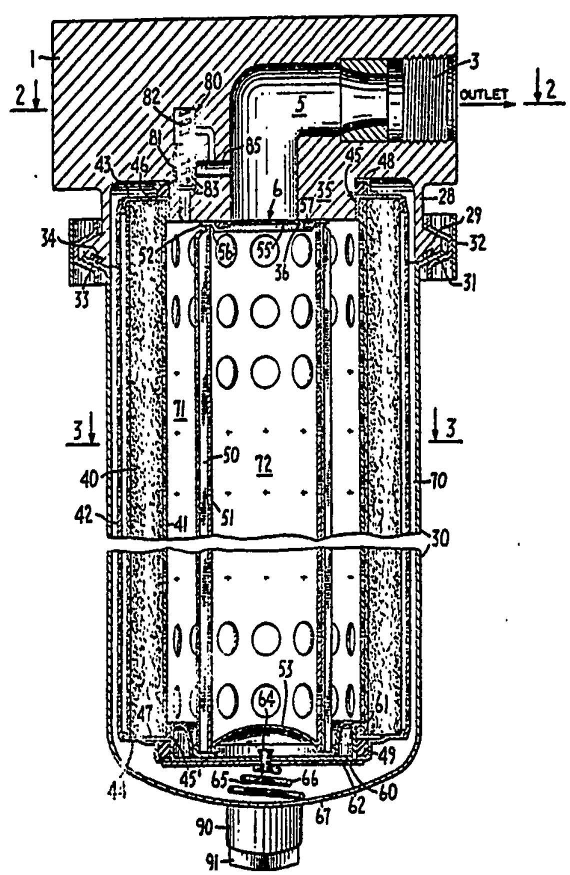


FIG. 2

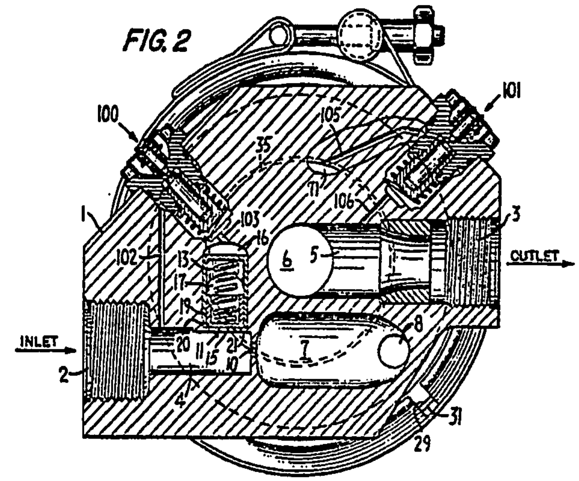


FIG. 3